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Selection of optimal milling modes for NiTi-TiB2 composite

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Abstract

At present, metal alloys and composites obtained using additive technologies are becoming more widespread. Such materials may have higher parameters of strength, hardness and wear resistance in comparison with conventional alloys. The creation of powder materials allows to obtain new properties of alloys by changing the structure of the material in a certain way. However, to ensure requirements for the accuracy of the shape, size and quality of the surfaces of products made of such materials, products should be processed by cutting on metal-cutting machines. Nevertheless, there are no recommendations on the choice of cutting tools and processing modes in literature. As part of this study, recommendations will be given on cutting conditions for processing of composite Inconel 625 with NiTi-TiB_2. The geometry of the end mills necessary for processing will be determined. The optimal speed, feed per tooth were selected when milling composite materials based on the conditions of tool wear resistance and the quality of the surface layer.

Keywords: Additive technology, composite, nickel, milling, laser sintering, machinability, cutting conditions, wear, cutting forces, tool life;

1. Introduction

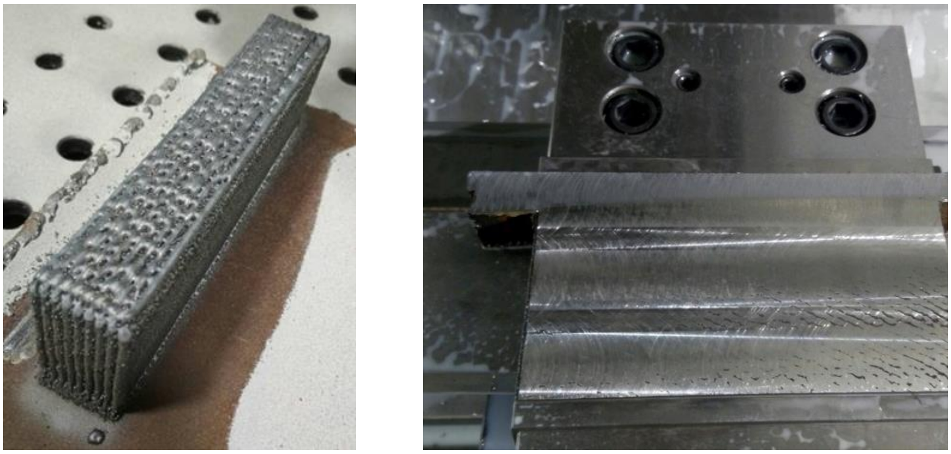
Additive technologies are used in the creation of products from composite materials with unique performance characteristics. Such materials may have higher parameters of strength, hardness and wear resistance in comparison with conventional alloys.

However, to meet the requirements for accuracy of shape, size and quality of surfaces, these products must be processed by cutting on metal-cutting machines, but there are no recommendations on the choice of cutting tools and processing modes in literature [1].

In the laboratory of high-energy systems and new technologies at TSU, a composite material Inconel 625 with NiTi-TiB_2, designed for the production of turbine blades and a method for its production using laser sintering were developed [4]. The image of the sintered billet is shown in Fig. 1.

The composite obtained in the study [4] has increased wear and heat resistance. It is new, so its machinability has not been studied yet. Since this material is designed for the manufacture of turbine blades, the main operation for its machining is milling.

The objective of this work was to determine the optimal modes of milling the composite by the end mills.



а б

Fig. 1. Image of a workpiece made of a Inconel 625 and NiTi-TiB_2 composite (a); image of a nickel alloy workpiece mounted in a vise on a milling machine (b)

2. Discussion

To assess the machinability of materials such indicators as cutting forces, the quality of the surface layer, tool wear, heat release during the cutting process, as well as type, shape and size of the cut chips are used [1].

Inconel 625 contains about 60% of nickel. Nickel-based alloys are heat resistant, they are used for products operating under extreme loads, so the material is difficult to process.

The material presented in this work is a composite of Inconel 625 powder with the addition of titanium diboride TiB2 in its matrix. Titanium diboride has high hardness and it is abrasive. Also, the resulting composite has high hardness comparable to hardened steel. There are no recommendations in literature on the choice of the geometry of the cutting tool and cutting conditions for such composites.

In the process of milling, the values of cutting speed and feed per tooth have the greatest influence on cutting forces, surface roughness and tool life [2]. Based on this, the main tasks of this work were posed:

1. selection of the end mill with the most optimal geometrical parameters from the conditions of wear resistance;
2. determination of the optimal cutting speed;
3. determination of the optimal value of feed per tooth.

3. Experiment

The work was performed on a vertical milling CNC machining center of the VF1 model, Haas (USA) (Fig. 2). Processing was carried out according to the schemes of climb and conventional milling. Tool wear was evaluated by the value of the facet of wear on the rear surface.

Fig. 2. Vertical milling CNC machining center of the VF1 model Haas

Solid carbide end mills manufactured by PK MION (Russia) were used as tools. For the experiment, three end mills with a diameter of 10 mm were selected:

• Milling cutter 3T643, designed for treating hardened steel with hardness over 60 HRC; front angle $\gamma = -7^{o}$, posterior angle $\alpha = 9^{o}$, screw-groove angle $\omega = 45^{o}$, number of teeth $z = 6$.

• ZhT641 milling cutter, designed for machining of titanium alloys; $\gamma = 4^{o}$, $\alpha = 10^{o}$, $\omega = 38^{o}$, $z = 4$.

• H630 milling cutter, designed for machining of stainless alloys; $\gamma = 12^{o}$, $\alpha = 10^{o}$, $\omega = 38^{o}$, $z = 4$.

Fig. 3. Solid carbide end mills

During the experiment, grooves were machined with each cutter (Fig. 4), while the milling depth was always equal to the diameter of the cutter, and the width was changed. In the first case, the milling width was B = 1 mm, with cutting speeds V = 15 m/min and V = 20 m/min with a feed to the tooth Sz = 0.02 mm/tooth, then at the same cutting speeds and the same width *B*, but with a larger feed per tooth Sz = 0.04 mm/tooth. In the second case, everything was repeated, but with a larger milling width B = 3 mm [3, 5]. The experimental conditions are presented in Table 1.

During the experiment, the cutting forces were measured to determine the optimal geometry of the cutter, as well as the feed to the tooth.

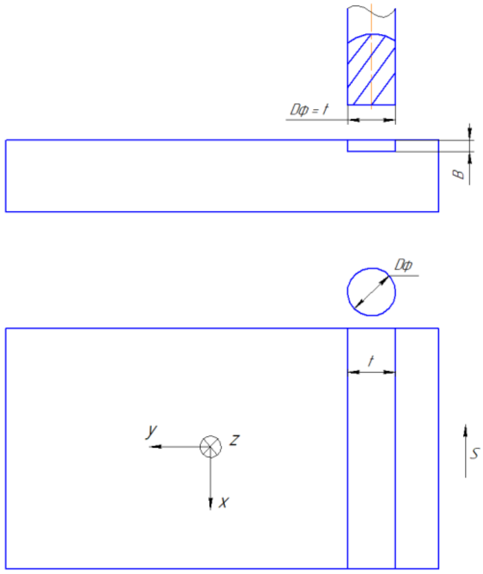
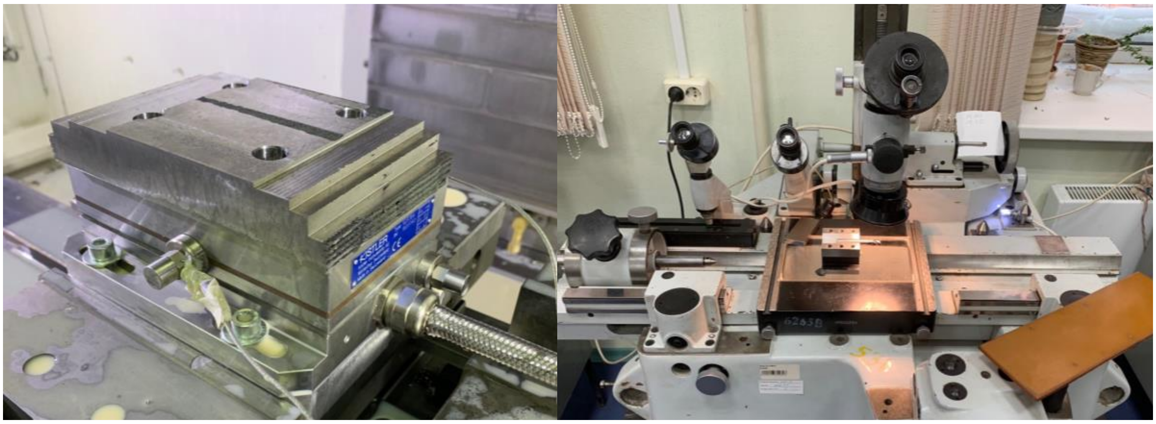


Fig. 4. Workpiece milling scheme

In the second part of the work to determine the optimal cutting speed, the processing was carried out in two modes: V_1 = 25 m/min and V_2 = 50 m/min. At the same time, the feed per tooth *Sz*, depth *t* and milling width *B* remained constant: Sz = 0.04 mm/tooth; t = 1 mm and B = 4 mm.

The tool wear was evaluated by facet wear on the back surface. The wear facet was measured using a Universal Measuring Microscope 21 (Fig. 5a). The measurement was performed with each tooth of the cutter, while two parameters were determined: maximum value which was always near the top of the tooth and average wear value which had a fairly stable value.

The cutting forces were determined using the Kistler 9257B dynamometer (Switzerland). The record of the forces was made during the whole time of milling. The measurements were carried out in three mutually perpendicular directions (Fig. 5, b). To evaluate the results, the total force acting in the plane of the dynamometer was used.



a b

Fig. 5. Workpiece on the dynamometer (a); Universal Measuring Microscope 21 (b)

The data collection and analysis were performed using DynoWare software (Kistler, Switzerland). The data processing was performed in Microsoft Excel.

4. Results

Table 1 presents measurements of cutting forces for three cutters with different geometries.

Table 1. Measurements of cutting forces.

Mill with γ = -7º; α = 9º, z = 6						
B, mm	V, m/min	Sz, mm/tooth	Sм, mm/min	Px, H	Py, H	Pz, H
1	15	0.02	58	111	106	-6
1	20	0.02	77	98	115	4.6
1	15	0.04	115	140.5	164.5	15.5
1	20	0.04	150	131	155	12
3	15	0.02	58	282	330	13
3	20	0.02	77	281	319	5
3	15	0.04	115	363	464	25.7
3	20	0.04	150	361	460	28.5
Mill with γ = 4º; α = 10º, z = 4						
1	15	0.02	40	66	76	9
1	20	0.02	50	67	72	11.8
1	15	0.04	77	86.5	106	12.1
1	20	0.04	102	79	101	11
3	15	0.02	40	192	203	5
3	20	0.02	50	212	205,5	4.9
3	15	0.04	77	257	286	16
3	20	0.04	102	288	294	14.8
Mill with γ = 12º; α = 10º, z = 4						
1	15	0.02	40	50	52	0.3
1	20	0.02	50	65	64	7
1	15	0.04	77	90	101	7
1	20	0.04	102	95.5	100	6.5
3	15	0.02	40	191	194	9.4
3	20	0.02	50	216	203	8.7
3	15	0.04	77	252	292.5	21
3	20	0.04	102	261.5	320.5	23

According to the results of measuring the cutting forces, the following conclusions can be drawn:

• The greatest cutting forces arose when machining with a 3T643 milling cutter, which is understandable, because this cutter has 2 more teeth, which means a larger number of teeth are in contact with the workpiece at the same time. It is also possible to assume that the increase in cutting force is caused by negative rake angles.

• Changes in cutting speed in the selected range from 15 to 20 m/min do not affect the cutting forces.

• Changing the feed per tooth twice from 0.02 to 0.04 mm/tooth, the cutting force increases by about 40%.

• Both milling cutters with positive geometry have similar cutting forces, but the H630 milling cutter experienced much greater vibrations. The ZhT641 mill is designed for processing of heat-resistant and titanium alloys, which include the studied composite, therefore it was chosen as the optimal one.

According to the results of experiments on choosing the optimal speed, it is clear that milling at a speed of 50 m/min, there is practically no zone of normal wear, the resistance of the cutter is not more than 8 minutes, and at a speed of 25 m/min the resistance is more than 25 minutes (Fig. 6).

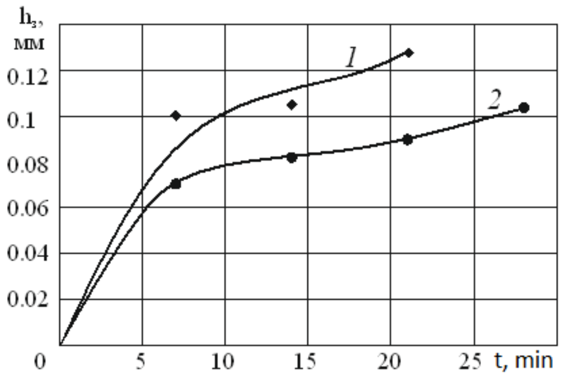


Fig. 6. Dependency graph of the amount of wear on the rear surface versus time: 1 - V = 50 m/min; 2 – V = 25 m/min

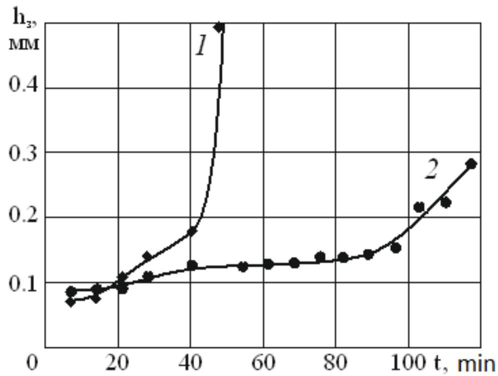


Fig. 7. Dependency graph of the amount of wear on the rear surface from the scheme of work: 1 – mill №1; 2 – mill №2

5. Conclusion

The composite Inconel 625 and NiTi-TiB_2 presented in this work can be effectively machined by carbide mills designed for machining heat-resistant steels and alloys. It was found that the optimal cutting speed for milling is V = 25 m/min, while the optimal feed per tooth is Sz = 0.04 mm / tooth. With these cutting modes, tool life is more than 100 minute.

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